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M 16. IMPROVING BOILER PERFORMANCE WITH MODIFIED BOILER CONTROL SYSTEMS

By

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Abstract

For timely processing of the crop, sugar factories need boiler stations that can reliably produce steam when fired with fuel of variable quality. The control systems installed on most sugar factory boilers have changed little in the last thirty years and in some cases the default control system response to changes in fuel and/or fuel quality is not correct and operator intervention is required to prevent factory stoppages or reductions in crushing rate caused by poor combustion.

Some factories have recently modified their boiler control systems for improved combustion performance and reduced maintenance costs. This paper describes testing carried out to evaluate some of these control system modifications and identifies boiler control system changes that can be applied more widely in the sugar industry.

Introduction

Boiler station problems are a common cause of factory stops and reduced throughput. Some of these issues arise because a boiler cannot respond quickly enough or in an appropriate manner to changes in fuel quality and factory steam demand. Operator intervention is often required to prevent combustion problems escalating into serious issues such as large furnace pressure fluctuations and boiler shutdowns due to extinguishment of the fire.

The cogeneration boilers at the Broadwater and Condong sugar factories experienced combustion problems associated with fuel changes. For example, when the fuel changed from bagasse to woodchip after a crushing stoppage, the air to fuel ratio would become too low and this would cause build up of fuel on the grate, loss of steam pressure and dark smoke emissions. To address these problems, Broadwater Mill engaged an external consultant to carry out boiler control system modifications (Moller and Ironside, 2011). Most of these control system modifications were subsequently implemented on the same design cogeneration boiler at Condong Mill.

Background

Most control systems for sugar factory boilers in Australia are now microprocessor-based but the basic control approach used (Dixon, 1981; Magasiner, 1968; Williams, 1982) has changed little over the last few decades. Model-based control has been investigated for biomass boilers (Masa *et al.*, 2011; Sun *et al.*, 2010) and there have been studies on control approaches for emissions reduction (Hrdlička and Bohumil, 2011). Alternative technologies for steam temperature control have been proposed for dual bagasse/coal-fired boilers (Ash, 2012). However there appears to be little if any published work on implemented control system modifications as major as the recent changes to the Broadwater and Condong cogeneration boilers (Moller and Ironside, 2011). The main components of these control system modifications are as follows, more detailed descriptions are given elsewhere (Mann, 2013; Moller and Ironside, 2011):

Calorific value corrector

The calorific value (CV) corrector manages the feeder speed changes brought about by changes in the fuel's calorific density so that the output of the boiler master controller only has to change when the factory steam demand changes. The CV corrector is a proportional-integral-derivative (PID) controller that outputs a multiplier that is applied to the feeder speed determined by the output of the boiler master (using a feeder speed curve). The inputs to this PID controller are steam flow calculated from the boiler master and the measured steam flow both expressed as a percentage of the boiler's maximum continuous rating (MCR). When the measured steam flow is greater than the steam flow calculated from the boiler master the multiplier is reduced and vice versa. With the CV corrector managing the feeder speed changes brought about by changes in the fuel calorific density (heating value per unit volume), the air flow will correlate more strongly with the boiler steam output than the feeder speed. This is the preferred relationship because fuels with higher calorific density such as woodchip tend to burn on the grate and require a higher air to fuel ratio.

Steam temperature control

Most cogeneration boilers with two-stage superheaters have a water spray for temperature control between the two stages. The flow through the water spray control valve is adjusted to keep the final steam temperature in the range required by the turbine(s). When the main flame is taller and higher in the furnace, the heat transfer to the superheater tubes increases and more spray water flow is required to keep the final steam temperature within the required range. Conversely, when the flame is shorter and lower in the furnace, less spray water is required.

With the modified control system, the spray water control valve position can be controlled to an operator-supplied set point by adjusting the secondary air supply pressure (using a damper). For example, if the flame is high in the furnace the spray water control valve may need to be 50% open to keep the final steam temperature within the required range. If this position is outside the range for optimal control of spray water flow, the operator may want to adjust the spray water control valve to a position where better control can be achieved. This is done by increasing the secondary air supply pressure and therefore secondary air flow to the furnace. The flue gas oxygen trim control loop (installed on many of the newer boilers) then reduces the quantity of air entering through the grate to keep the total air flow to the furnace constant. The reduced grate air flow will lower the position of the flame in the furnace and the increased secondary air flow will bend the flame over and reduce its height (as pointed out by Condong Mill staff). Having a lower and shorter flame will reduce heat transfer to the superheater tubes and therefore the amount of spray water required. The secondary air pressure and therefore secondary air flow is increased and the grate air flow reduced until the spray water control valve is at its optimal opening.

Pneumatic distribution air control

The fuels used in the Condong and Broadwater cogeneration boilers have a wide range of densities and will be projected different distances into the furnace for the same distributor air flow. Heavier fuels such as woodchip need more distributor air flow compared to that required to project bagasse an adequate distance into the furnace. The Condong and Broadwater cogeneration boilers allow the operator to set the distributor air supply pressure using the distributor air fan outlet damper. After the control system modifications, the distributor air supply pressure set point was determined from the output of the CV corrector. When a fuel with a low CV corrector value such as woodchip was being used, the distributor air supply pressure set point will be high because a heavier fuel needs a higher distributor air pressure. With typical bagasse having a CV corrector value of 1.0, the distributor air supply pressure set point would be lower. If the CV corrector value is above 1.0 then that is indicative of wet bagasse and a higher distributor air supply pressure would be used. The selection of distributor air supply pressure for different CV corrector values was done by the modified control system. This system operates with some success at Broadwater Mill but was never implemented at Condong Mill due to concerns about how the system would perform when the boiler was fired with dry sawdust.

Grate metal temperature control

Furnace grates, especially the moving grates installed in the Condong and Broadwater cogeneration boilers, are susceptible to failure if the grate metal temperatures get too high. To help prevent this occurring, a control loop was set up that adjusted the air heater air bypass damper position to maintain the average grate metal temperature at an operator supplied set point. When the average grate metal temperature gets too high, the air heater air bypass damper moves to a more open position. This reduces the temperature of the combustion air entering through the grate and therefore the grate metal temperatures.

Dew point corrosion control

To reduce the risk of dew point corrosion, Condong has installed a controller to maintain the metal temperature at the cold side of the low temperature air heater above 80°C. The metal temperature is assumed to be the average of the ambient air temperature and the low temperature air heater gas exit temperature. When this metal temperature falls below 80°C, hot air from the exit of the high temperature air heater is recirculated and mixed with the ambient air entering the low temperature air heater. A damper is installed to regulate the flow of hot air from the air exit of the high temperature air heater to the inlet of the forced draft fan.

Testing program

Testing of the Condong cogeneration boiler was carried out during the 2012 crushing season to evaluate some of the foregoing boiler control system modifications and assess whether these modifications could be more widely applicable. The focus was on the control system modifications implemented on the Condong cogeneration boiler that affect boiler combustion performance, i.e. the CV corrector and the steam temperature control using overfire air with the boiler running on bagasse.

The testing included gas analyser measurements at the exit of the low temperature air heater and collection of boiler data for different control system settings. Care was taken to constrain the changes to boiler control system settings so as not to unduly disrupt the operations of the cogeneration plant or factory. The parts of the testing program related to how the boiler handles fuel and steam load changes are summarised in Table 1.

Table 1 – Summary of part of the testing program for the Condong cogeneration boiler during the 2012 crushing season.

Date	Tests
15-10-2012	Initially the boiler was transitioning from 100% camphor laurel fuel to 100% bagasse fuel. During this transition period: • Gas analyser measurements were taken from a sampling port at the gas exit of the low temperature air heater at five-minute intervals (approximately).
18-10-2012	The boiler was being fired with 100% bagasse fuel during the tests which included: • Gas analyser measurements while increasing the electricity generation from 13 MW to 30 MW and then decreasing the electricity generation to 16 MW. During these measurements the secondary air supply pressure was automatically adjusted to maintain a constant spray valve opening (normal control system settings); and • Gas analyser measurements while increasing the electricity generation from 16 MW to 30 MW and then decreasing the electricity generation to 18 MW. During these measurements the secondary air supply pressure set point was equal to 3.8 kPa instead of being automatically adjusted to maintain a constant spray valve opening.

Boiler operating data at one-second intervals were collected during all the tests. The original plan was to include fuel and ash sampling as part of the testing program. However after further consideration it was decided to not include any fuel or ash sampling because the responses of the boiler to changes in the fuel and steam demand were expected to be of the order of minutes - similar to the time lags in the fuel feeding and ash collection systems. Accordingly, multiple sampling of the fuel and ash streams, which is required to produce representative fuel and ash compositions, would not have been practical. Instead, changes in logged data and sampled gas compositions were used to assess the effect of a change. Carbon monoxide (CO) concentrations in the flue gas are a commonly used means of assessing combustion performance and in some cases have been used as part of a boiler control scheme (Omerod and Read, 1979). High CO levels indicate poor combustion and nearly always correspond to high combustible matter contents in the ash (losses on ignition).

Figure 1 shows a relationship between ash loss on ignition and CO concentrations derived from efficiency tests carried out on the Broadwater Mill cogeneration boiler with bagasse firing in 2008.

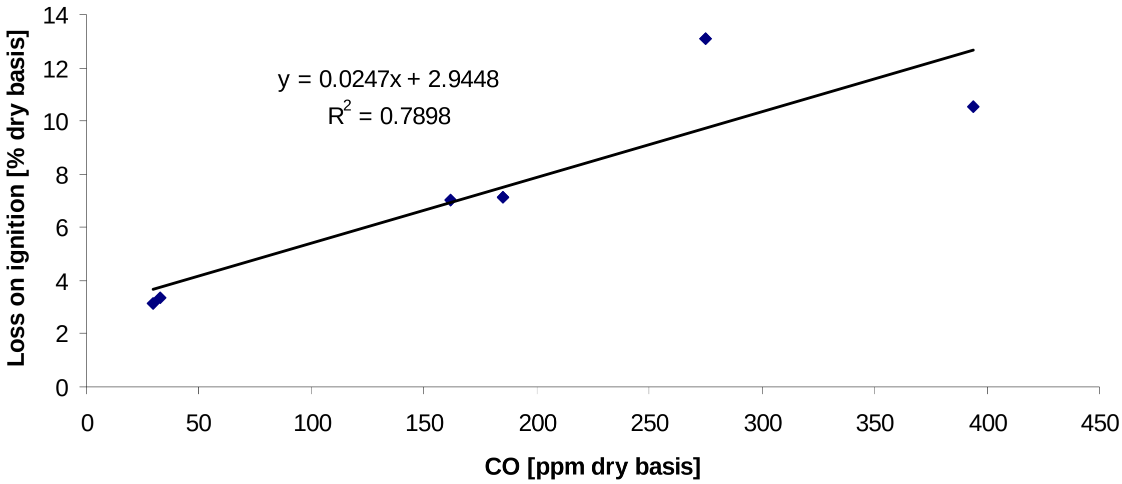

Fig 1 – Relationship between measured ash loss on ignition and CO concentration derived from efficiency tests carried out on the Broadwater cogeneration boiler in 2008.

The ash contents in the bagasse samples from the efficiency tests conducted in 2008 can be used to convert the losses on ignition values in Figure 1 to unburnt fuel percentages. These are plotted against CO concentrations in Figure 2. The correlation between the percentage unburnt solid fuel and the CO concentration in Figure 2 is not strong but it does provide a means of estimating the unburnt solid fuel efficiency loss, which is difficult to measure continuously, from the measured CO concentration. The concentration of CO in the flue gas can be measured continuously so Figure 2 provides a convenient means of estimating how unburnt solid fuel losses change with time.

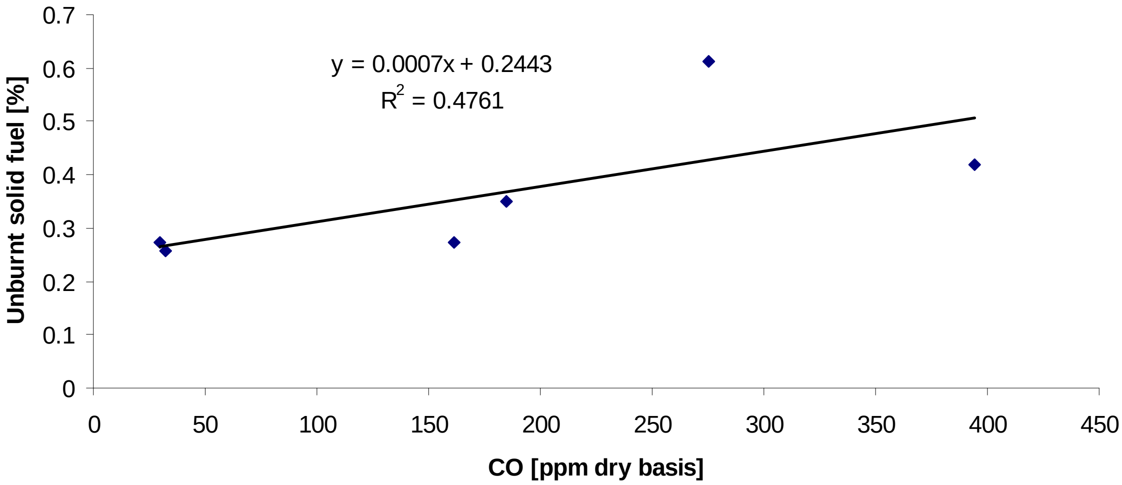

Fig 2 – Relationship between calculated unburnt solid fuel percentage and measured carbon monoxide concentration derived from efficiency tests carried out on the Broadwater cogeneration boiler in 2008.

The Condong and Broadwater cogeneration boilers are an identical design so it was assumed in this work that the relationships in Figures 1 and 2 also hold for the Condong cogeneration boiler. The CO measurements were used to estimate the total efficiency loss due to incomplete combustion that takes into account CO loss and unburnt solid fuel loss, the sum of which is referred to hereafter as 'combustion efficiency loss'.

Results

Changing fuel trial

Figure 3 shows the variation of the steam flow (assumed to be the sum of the logged feedwater and desuperheater flows)[1] and the measured oxygen (O_2) concentrations at the gas exit of the low temperature air heater, of the Condong cogeneration boiler as the fuel was transitioned from camphor laurel woodchip to bagasse. Over this period (slightly longer than one hour) the steam flow varied from 69 to 92 t/h and the O_2 concentration in the flue gas ranged from 7.9 to 10.4%. Higher O_2 concentrations tend to correspond with lower steam flows but over this time period the boiler control system was able to prevent large swings in the air to fuel ratio. Note that all the O_2 concentrations measured at the exit of the low temperature air heater will be higher than the O_2 concentrations in the furnace due to air heater leakage.

Figure 4 shows the measured CO and NO_x[2] concentrations at the gas exit of the low temperature air heater of the Condong cogeneration boiler during this transition period. With camphor laurel fuel, the CO concentrations are relatively high and the NO_x concentrations are relatively low. With bagasse firing, the CO concentrations are low and the NO_x concentrations are higher than those for camphor laurel firing. These measurements are consistent with expectations because camphor laurel burns primarily on the grate where the poorer mixing and lower temperatures would increase CO concentrations. With bagasse firing, most combustion occurs in suspension and peak temperatures would be expected to be higher. Higher peak temperatures normally increase NO_x concentrations.

The CV corrector was able to manage the transition from camphor laurel firing to bagasse firing without any combustion stability problems or swings in the air to fuel ratio serious enough to cause dark smoke emissions. It was not possible to carry out measurements when the boiler was transitioning from bagasse firing to woodchip (camphor laurel or sawmill residue) firing but Condong Mill reported that the boiler manages this transition much better after the control system modifications.

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[1] The steam flow measurement from the boiler instrumentation was not considered reliable by Condong Mill staff.

[2] NO_x includes nitric oxide (NO) and nitrogen dioxide (NO_2).

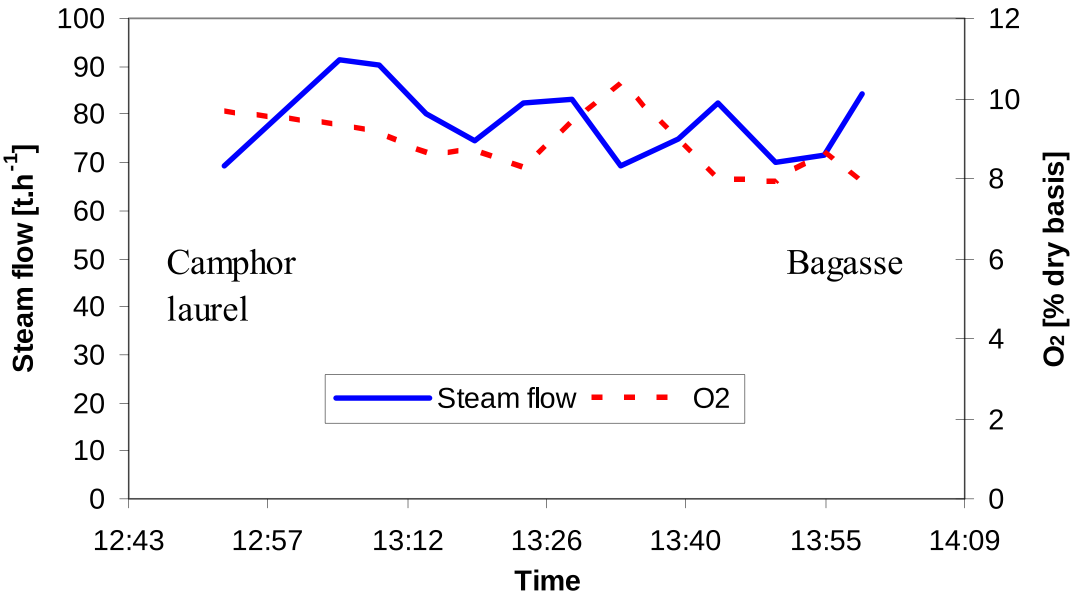

Fig 3 – Variation of the recorded steam flow (t/h) and measured flue gas O_2 concentration (% dry basis) at the gas exit of the low temperature air heater of the Condong cogeneration boiler as the fuel was transitioning from camphor laurel to bagasse.

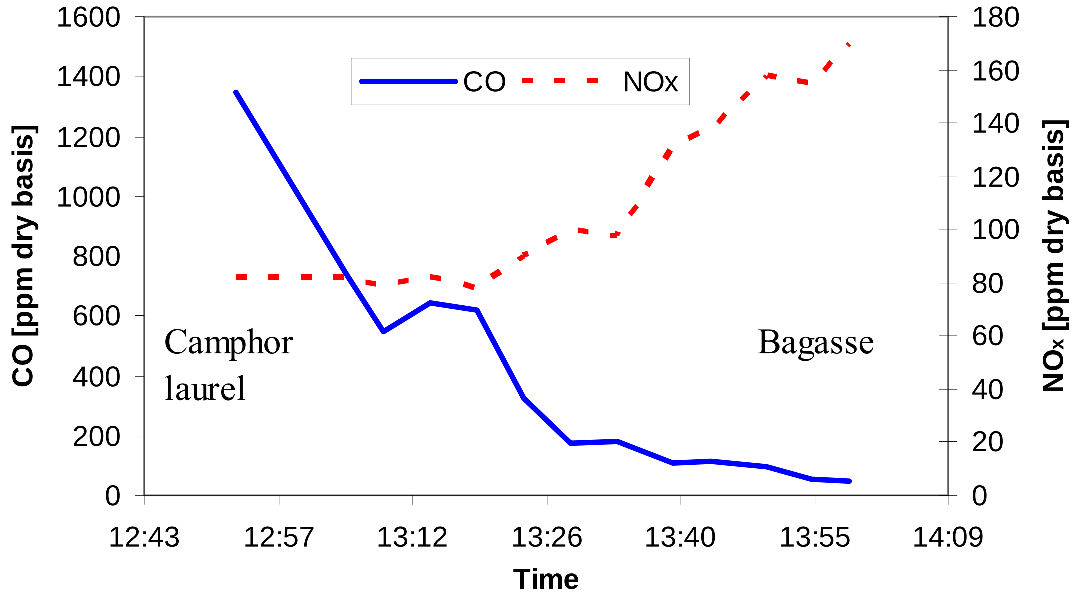

Fig 4 – Variation of the measured flue gas CO and NO_x concentrations (ppm dry basis) at the gas exit of the low temperature air heater of the Condong cogeneration boiler as the fuel was transitioning from camphor laurel to bagasse.

Varying steam output trials

During the trials on the 18-10-2012 the boiler was firing bagasse only and the steam output of the boiler was varied by changing the amount of electricity generated. This was done when the secondary air supply pressure was automatically adjusted to maintain a constant spray valve opening (normal control system settings) and when the secondary air supply pressure was in manual mode with a set point equal to

3.8 kPa. During the initial measurements (secondary air supply pressure in automatic mode) the electricity generation was increased from 13 MW to 30 MW and then decreased to 16 MW. During the second set of measurements (secondary air supply pressure in manual mode) the electricity generation was increased from 16 MW to 30 MW and then decreased to 18 MW.

A spreadsheet model was set up to use the CO readings from each set of measurements, the relationship between unburnt solid fuel loss and CO concentration in Figure 2 and the assumed bagasse composition and heating value in Table 2 to calculate the combustion efficiency loss (CO loss plus unburnt loss) during each set of measurements.

Table 2 – Assumed bagasse composition and heating value used in the combustion efficiency loss calculations.

Moisture	(% as received)	47.4
Ash	(% as received)	4.36
Ultimate analysis	(dry ash free)	
Carbon	(%)	49.8
Hydrogen	(%)	5.9
Nitrogen	(%)	0.2
Sulphur	(%)	0.1
Oxygen	(%)	44.0
Gross calorific value	(kJ/kg)	9 584

The calculated variation of combustion efficiency loss and the corresponding steam flows for each set of measurements are plotted in Figures 5 and 6. The calculated combustion efficiency losses when the secondary air supply pressure was in manual mode with a set point of 3.8 kPa (with the logged secondary air supply pressure varying from 3.6 to 3.9 kPa) were significantly lower than the calculated combustion efficiency losses when the secondary air supply pressure was in automatic mode (with the logged secondary air supply pressure varying from 0.2 to 1.6 kPa). Furthermore, with the increased secondary air supply pressure, there were fewer fluctuations in steam flow and the changes in electricity generation could be made more quickly.

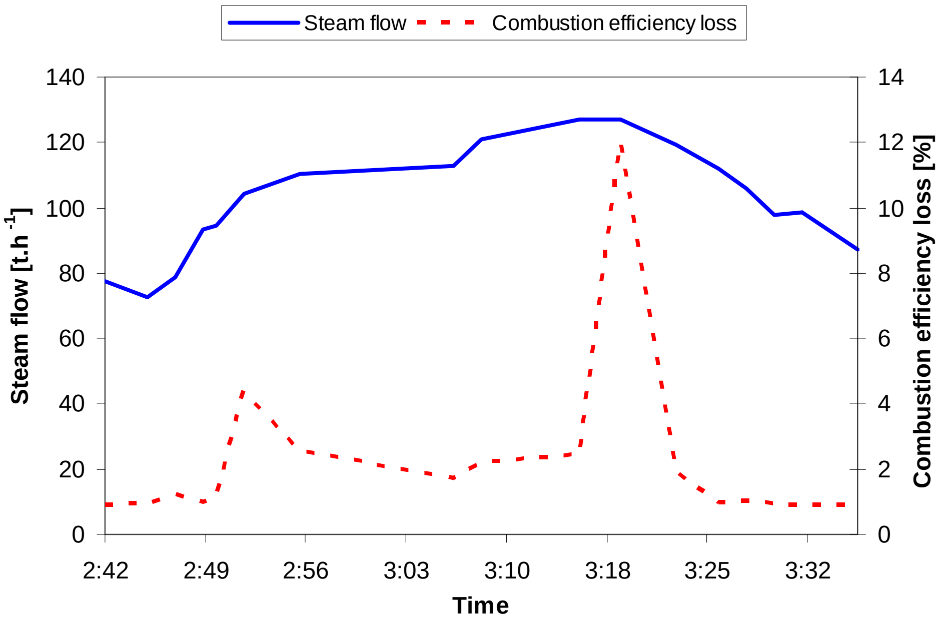

Fig 5 – Recorded steam flow (t/h) and calculated combustion efficiency loss (%) from the measurements at the gas exit of the low temperature air heater of the Condong cogeneration boiler on the 18-10-2012 for bagasse firing with the secondary air supply pressure in automatic mode.

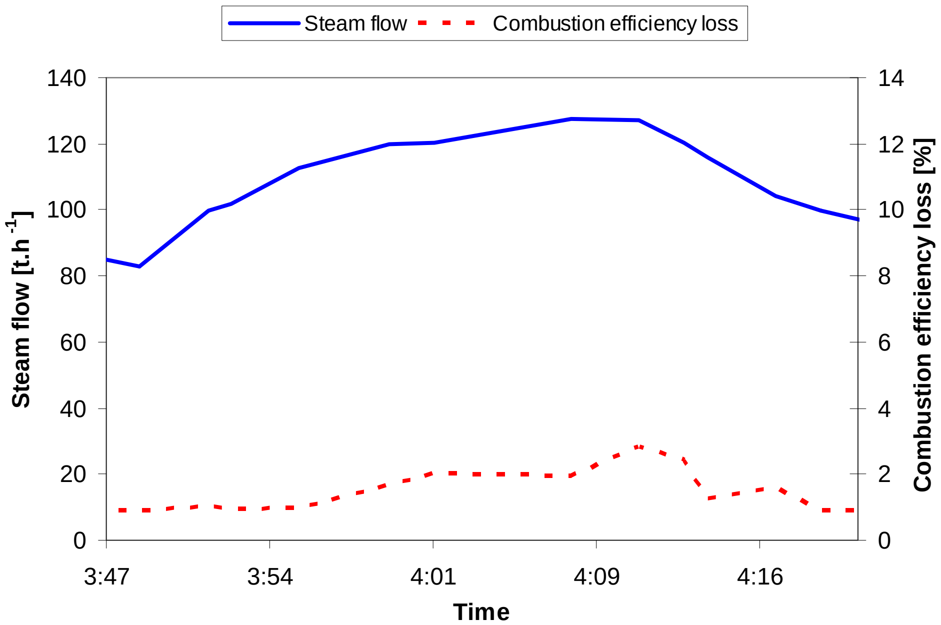

Fig 6 – Recorded steam flow (t/h) and calculated combustion efficiency loss (%) from the measurements at the gas exit of the low temperature air heater of the Condong cogeneration boiler on the 18-10-2012 for bagasse firing with the secondary air supply pressure in manual mode with a set point of 3.8 kPa.

Table 3 compares the means and standard deviations of the logged steam temperatures and spray water flows during these tests with the secondary air supply pressure automatically adjusted to keep the spray water valve in its optimum position and with the secondary air supply pressure in manual mode with a set point of 3.8 kPa. When the secondary air supply pressure was in manual mode the steam temperature was controlled solely by the spray water valve position. In manual mode, with the higher secondary air supply pressure, the mean steam temperature is lower (due to the flame being lower in the furnace, shorter and bent away from the superheaters) but the standard deviation of the logged steam temperatures was higher. The mean and standard deviations of the spray water flows were lower when the secondary air supply pressure was in manual mode.

Table 3 – Means and standard deviations of the logged steam temperatures during the tests on the 18-10-2012 (bagasse firing) with the secondary air supply pressure in automatic mode and with the secondary air supply pressure in manual mode with a 3.8 kPa set point.

Secondary air supply pressure	Steam temperature (°C)		Spray water flow (t/h)	
	Mean	Standard deviation	Mean	Standard deviation
Automatic	512.6	10.4	4.5	1.7
Manual with a 3.8 kPa set point	500.0	42.6	3.8	1.3

It is clear from Table 3 that the spray water control valve struggled to maintain tight control of the steam temperature when the secondary air supply pressure was in manual mode with a 3.8 kPa set point. With the flame lower in the furnace, shorter and bent away from the superheater tubes, less spray water was required and the spray water control valve was in a more closed position from where it was less able to regulate the spray water flow quickly enough for good control of steam temperature. Much tighter control of the steam temperature was achieved when the secondary air supply pressure was in automatic mode. In automatic mode the secondary air supply varied from approximately 0.2 kPa when the steam flow was less than 90 t/h to 1.5 kPa when the steam flow reached 127 t/h. It appears that for this boiler, the optimum spray water valve position was obtained with relatively low secondary air supply pressures but the best combustion performance was achieved with higher secondary air supply pressures.

Conclusions

The data collected from and the measurements carried out on the Condong cogeneration boiler have confirmed the effectiveness of the CV corrector for maintaining stable combustion performance when transitioning from camphor laurel fuel to bagasse fuel. The CV corrector appears to be an effective means of managing the transition between different types of fuel and could be used more widely in boilers that use auxiliary fuels.

The approach of using the secondary air supply pressure to adjust the position, size and shape of the flame in the furnace and maintain a constant attemperator spray valve opening improved the control of steam temperature. Adjusting the secondary air supply pressure for better steam temperature control will be applicable to boilers that supply steam to turbines with strict steam temperature requirements.

However, for the Condong cogeneration boiler, good steam temperature control was achieved with low secondary air supply pressures while best combustion performance was achieved with higher secondary air supply pressures. Given the improved combustion performance at higher secondary air supply pressures shown by the measurements in this work, a modified control system that automatically increases secondary air supply pressure (while using O_2 to maintain a constant air to fuel ratio) at high boiler steam outputs or during periods of combustion instability could have more widespread application.

While not specifically evaluated in the testing program, the grate temperature and dew point corrosion control system modifications could also be more widely implemented in sugar factory boilers.

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REFERENCES

Ash NC (2012) Superheater performance in dual fired industrial watertube boilers with a comparison of two attemperator technologies. *Proceedings of the South African Sugar Technologists' Association* **42**, 91-101.

Dixon TF (1981) Review of boiler control systems. SRI Technical Circular 62. (Sugar Research Institute, Mackay).

Hrdlička J, Bohumil Š (2011) Test results from sugar cane bagasse and high fiber cane co-fired with fossil fuels. *International Journal of Energy* **5**, 62-69.

Magasiner N (1968) Automatic control of boiler plant in the cane sugar industry. *Proceedings of the South African Sugar Technologists' Association* **42**, 91-101.

Mann AP (2013) Evaluation of boiler control system modifications. SRI Technical Report 4/13.

Masa V, Pavlas M, Svarc I (2011) Mathematical model of biomass boiler for control purposes. *Chemical Engineering Transactions* **25**, 743-748.

Moller D, Ironside R (2011) Advanced controls for a biomass boiler. *Proceedings of the Australian Society of Sugar Cane Technologists* **33**, (electronic format) 5 pp.

Omerod WG, Read AW (1979) An improved method of combustion control of coal-fired boilers using flue gas carbon monoxide analysis. *Journal of the Institute of Energy* **52**, 23-26.

Sun J, Wang J, Huajing F, Wu Y-m (2010) Study on the fuzzy adaptive PID algorithm for control system of biomass boiler. In 'International Conference on Measuring Technology and Mechatronics Automation' Changsha City, China, 2010. Vol 3, pp. 661-664. (Institute of Electrical and Electronic Engineers).

Williams EG (1982) Stable automatic combustion control of mill boilers. *Proceedings of the Australian Society of Sugar Cane Technologists* **4**, 197-203.